Biological Services Program

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Air Pollution and Acid Rain,
Report No. 1

Effects of Air Emissions on Wildlife Resources

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2. To gather, analyze, and present information that will aid decision makers in the identification and resolution of problems associated with major land and water use changes.

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Biolgoical Services Program

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Air Pollution and Acid Rain,
Report No. 1

EFFECTS OF AIR EMISSIONS ON WILDLIFE RESOURCES

by

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PREFACE

The passage of the Clean Air Act and its 1977 Amendments resulted in a number of regulations to protect air quality. Incorporated in this legislation is a new responsibility for federal land managers, including the Fish and Wildlife Service, to assess and evaluate impacts of air quality degradation on "air quality related values" on certain lands under their jurisdiction. Inherent in meeting this responsibility is the need for comprehensive and current information on ecological effects of air pollution, including acidic precipitation.

Since the early 1970's ecological research in air pollution and acid rain has steadily increased and a number of ecosystem scale studies have been initiated. As the results of these studies and other topical research become available, the need exists within the Service and other groups for analysis, interpretation, and concise summaries of this information as it relates to the potential impacts to fish and wildlife resources. Effects of Air Emissions on Wildlife Resources addresses this need in part by providing up-to-date information in a format appropriate to wildlife resource evaluation. The report is intended to assist biologists and decision makers in assessment of ecological impacts and enable their effective input into the regulatory process.

Suggestions or comments regarding the report should be addressed to:

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ABSTRACT

Incidents of injury and death to wildlife as a result of air emissions have been documented for over 90 years. This report summarizes the known effects of air emissions on wildlife resources. Contamination of wildlife by air emissions can occur in three ways: inhalation, absorption, and ingestion. Ingestion is the most common mode of contamination. Air emissions have caused mortality, debilitating injury, disease, and lowered resistance to stress. Wildlife are indirectly affected by contamination of their food resources and by habitat loss. Wildlife can serve as biological indicators of air quality. Some implications are discussed for wildlife management in regions affected by air emissions.

INTRODUCTION

Recent Federal legislation, namely the 1977 Clean Air Act Amendments and the 1978 Endangered Species Act Amendments, has focused attention on the effects of air emissions on wildlife. An increasing number of instances of adverse impacts of air emissions on wildlife have been reported (Tables 1 and 2). This increase in the number of reported incidents appears to be due not only to an increase in air emissions but to a better understanding of air pollution effects, broader communications, and a greater interest in reporting problems relating to air pollution (Heck and Brandt 1977).

Injuries to wildlife from air emissions were reported as early as the 1880's. One of the earliest reports (1887) involves the death of fallow deer (Dama dama) from arsenic emissions due to a silver foundry in Germany (Tendron 1964). The classic example of early scientific interest but little widespread concern involves "industrial melanism." As early as 1900 the Royal Society of London was charged to investigate the phenomena of industrial melanism. Sulfur dioxide and particulates from coal-burning industries killed lichens growing on trees, soiled the bark of trees, and ultimately changed the natural background color of the habitat of many species of insects. The protective advantage for the natural cryptic coloration of these insects was lost. New population morphs with color patterns suited to the polluted environment evolved as a result of the selective predation by birds (Kettlewell 1973). This incident is more recognized for its demonstration of "natural" selection than as an environmental problem.

One of the more detailed early reports on the harmful effects of air pollution is from Germany. Widespread killing of game animals by arsenic emissions occurred in the Tharandt forest of Germany in 1936. Between 60 to 70 percent of the red deer (Cervus elephus), roe deer (Capreolus capreolus),

and wild rabbits (Oryctolagus cuniculus) died. The deer exhibited defective hair growth and antler formation, cirrhosis of the liver and spleen, and emaciation (Prell 1936).

Since the end of the 19th century, more than 100 air pollution episodes involving domestic and free-living animals have been reported (Newman 1979). Seventy-five percent of these episodes have been recorded in the last 25 years. Approximately one-quarter of these incidents involved vertebrate wildlife. The paucity of reports on wildlife is more a result of economic bias to report injury and death of domestic animals than some innate resistance of wildlife to air pollution. For example, in the early 1900's Harkins and Swain (1908) and Formad (1908) reported that the injury and death of several thousand cattle and horses in rural Montana were caused by arsenic emissions from a smelter. No mention was made of injury or death to deer or other wildlife plentiful in the area, although more recent studies on deer and other wildlife species have shown them to be very sensitive to arsenic (Prell 1936; Tendron 1964; Hais and Masek 1969). Overall, the majority of wildlife incidents reported involved deer and small birds (Tables 1 and 2). These groups are not necessarily more sensitive but are more likely to be monitored. This situation is especially true of deer, which is a widely managed game species. The status and health of small birds are not only of scientific concern but are also of more widespread public interest.

This report summarizes the known effects of air emissions on wildlife resources. For this discussion, air emissions are limited to nonradiological and nonpesticidal emissions.

Table 1. Early Air Pollution Incidents Involving Wildlife (Newman 1979)

Date	Location	Species	Pollutant(s) and source(s)	Reported atmospheric levels or tissue concentrations	Effects	References
1887	Germany	Fallow deer	Arsenic, smelter	NA[a]	Death of fallow deer	Tendron (1964)
1900	England	Moths	SO_2 and particulates, power plants, and other industries	NA	Melanism, change in population genetics	Kettlewell (1973)
1927	Texas, U.S.A.	Small birds	H_2S, oil wells	Up to 139,059 ug/m^3 in air	Death to large number of birds	Yont and Sayers (1927)
1936	Germany	Rabbits, red deer, and roe deer	Arsenic, smelter	NA	Death to 60-70% of individuals	Prell (1936)
1957	Utah, U.S.A.	Mule deer	Fluoride, aluminum plant	1,500 ppm in bones	Fluorosis	Robinette *et al.* (1957)

[a] NA = Not available.

Table 2. Recent Incidents Involving the Adverse Effects of Industrial Air Pollutants on Vertebrate Wildlife (Adapted from Newman 1979)

Date	Location	Species	Pollutant(s) and source(s)	Reported atmospheric levels or tissue concentrations[a]	Effects	References
1963	South Africa	Baboons and rats	Asbestos, mine	NA[b]	Respiratory lesions	Webster (1963)
1965	Czechoslovakia	Small Birds	Fluoride, aluminum plant	Up to 139 ug/m^3 in air	Declining populations	Feriancova-Masarova & Kalivodova (1965)
1967	Ontario, Canada	White-tailed deer	Fluoride, industrial complex	Up to 7,125 ppm in bone and 1,200 ppm in water	Fluorosis	Karstad (1967)
1967	England	House martins, swifts	Particulates, coal-burning industries	<50 mg/m^3 particulates	Reduced populations recovering	Cramp and Gooders (1967); Gooders (1968)
1968	Czechoslovakia	House sparrows	Fluoride, aluminum plant	0.02 to 0.014 mg/m^3 in air	Biological concentration	Balazova & Hluchan (1969)
1969	Czechoslovakia	Red and roe deer	Arsenic, smelter	NA	Sickness and death	Hais & Masek (1969)
1970	California, U.S.A.	House sparrows	Photochemical oxidant smog, urban sources	NA	Respiratory lesions	Wellings (1970)
1971	British Columbia, Canada	Passerine birds	H_2S, pulp mill	NA	Death of hundreds of birds	Harris (1971)
1971	Czechoslovakia	Hares	SO_2 and fly ash, power plants and other industries	>0.15 mg SO_2/m^3 in air and 300 t/km^2/yr fly ash deposition	Hypocalcemia and hypoproteinesis	Novakova & Roubal (1971), Novakova et al. (1973)
1973	Japan	Sparrow	Cadmium, refinery	2.2 ppm in liver	Death of birds	Nishino et al. (1973)
1973	California, U.S.A.	Bighorn sheep	Oxidants, urban sources	Up to 0.37 ppm in air	Blindness	Light (1973)

Continued

Table 2 (Continued)

Date	Location	Species	Pollutant(s) and source(s)	Reported atmospheric levels or tissue concentrations[a]	Effects	References
1974	California, U.S.A.	Voles	Lead, urban sources	1.1 ppm in bone	Biological concentrations	Hirao & Patterson (1974)
1974	New Hampshire, U.S.A.	Mice and shrews	Lead, cadmium, and copper, industrial regions	Body conc. for Pb, Cu, and Cd of 2.7, 3.2, and 0.4 ug/g in mice; 2.6, 2.9, and 0.4 ug/g in shrews[c]	Biological concentrations	Schlesinger & Potter (1974)
1975	Japan	Larks	Air pollution, general industries	NA	Reduced populations	Miyamoto (1975)
1975	England	Sparrowhawks and song thrushes	Cadmium, smelter	Up to 387 ppm in kidney	Food chain magnification	Martin & Coughtrey (1975, 1976)
1975	California, U.S.A.	Small mammals	Oxidants, urban areas	NA	Reduced populations	Kolb & White (1975)
1975	Montana, U.S.A.	Mule and white-tail deer	Fluoride, aluminum plant	Up to 430 ppm in vegetation	Fluorosis	Kay et al. (1975)
1975	Poland	Roe deer	SO_2 and particulates, steel mill	80-450 t/km^2/yr particulates	Reduced antler quality	Jop (1979)
1976	Washington, U.S.A.	Black-tailed deer	Fluoride, aluminum plant	3,900 ppm in metatarsals	Fluorosis	Newman & Yu (1976)
1977	Czechoslovakia	House martins	SO_2, particulates, fluoride, and NO_x; power plants and other industries	NA	Reduced nesting	Newman (1977); Newman & Novakova (1979)
1977	England	Wood mice and bank voles	Mercury, chlor-alkali plant	37 to 124 ng/dm^2/d deposition	Biological concentration	Bull et al. (1977)

Continued

Table 2 (Concluded)

Date	Location	Species	Pollutant(s) and source(s)	Reported atmospheric levels or tissue concentrations[a]	Effects	References
1978	England	Field mice and voles	Fluoride, mining	Up to 7,000 ppm in bone	Biological concentration	Wright et al. (1978)
1979	Washington, USA	Black-tailed deer	Fluoride, aluminum plant	Up to 90 ppm in vegetation	Browse contamination	Newman and Murphy (1979)
1979	California, USA	Deer mice	Ozone	6.6 ppm for 12 hrs in lab air	Genetic change in sensitivity to ozone	Richkind (1979)

[a] Tissue concentrations on dry weight basis.
[b] NA = Not available.
[c] Tissue concentrations on wet weight basis.

PATHWAYS OF CONTAMINATION

The sources of atmospheric emissions or contaminants from industrial, agricultural, and forestry activities are numerous (U.S. Environmental Protection Agency 1977, 1978). The various kinds and combinations of emissions from these sources can be classified in two categories: particulates and gaseous emissions. The chemical and physical behaviors of these emissions are a function of the emission type, other associated emissions, the physical characteristics of the source, meteorological conditions, topography, and the nature of the vegetation surrounding the source (Lewis et al. 1978). Predicting the pathways of contamination and potential impacts and explaining observed impacts on wildlife requires a good understanding of the physical and chemical behavior of these contaminants. Numerous reviews such as Stern (1977) and the reports of U.S. Fish and Wildlife Service (Dvorak et al. 1978; Lewis et al. 1978) present a good introduction to the physical and chemical nature of air emissions.

There are three pathways for contamination of wildlife by air emissions: inhalation, adsorption, and ingestion. Inhalation involves the drawing into the lungs of gases or particulates. Wellings (1970) reported the occurrence of pulmonary anthracosis in urban versus rural sparrows (Passer domesticus) in California. No discussion was made of possible adverse effects other than the observed lung pathologies of the birds found in an urban environment with high particulate levels. One of the most startling examples of air pollution effects by inhalation was the die-off of 200 to 500 songbirds, near a pulp mill in British Columbia, which emitted high concentrations of hydrogen sulfide and other pollutants. The birds showed internal hemorrhaging in the lungs and liver (Harris 1971).

Adsorption of air emissions involves the adhesion of gases or particulates to the external surfaces or membranes, e.g., the cornea of eyes. Light (1973) reported a high incidence of blindness in bighorn sheep (Ovis canadensis) in mountain areas of California having high oxidant levels. Oxidants are known eye irritants in humans and laboratory animals. Investigators in Czechoslovakia (Novakova, personal communication) have observed premature aging of the cornea in hares (Lepus europaeus) in areas with heavy sulfur dioxide emissions and particulate deposition from power plants and other industries. These investigators postulated that the hares living in these areas are exposed to heavy particulate deposits on the ground and on the vegetation. As the hares move through the vegetation, these particulates are adsorbed on the eyes and cause corneal damage.

Ingestion is the most commonly reported of the three pathways of contamination for wildlife. Ingestion involves the swallowing of food or water contaminated by air emissions or swallowing of contaminants during grooming. Exposure can be through surface contamination of food or hair by

air emissions or through contaminated plant or animal tissues. Injury and death to wildlife from ingestion of contaminated food and water (Tables 1 and 2) have been reported in rabbits and deer from arsenic emissions (Prell 1936), in deer (Odocoileus sp.) from fluoride emissions (Karstad 1967; Newman and Yu 1976; Newman and Murphy 1979), and in sparrows from cadmium emissions (Nishino et al. 1973).

For any air emission incident, one or more of the pathways of contamination may be possible. For example, in Czechoslovakia, both adsorption and ingestion of particulate emissions by hares have adversely affected these animals.

DIRECT EFFECTS OF AIR EMISSIONS ON WILDLIFE

Several examples of the direct effects of air emissions were cited in the previous discussion. The direct effects can be either acute effects such as sudden mortality of songbirds from hydrogen sulfide or chronic effects such as fluorosis in deer from fluoride emissions. The magnitude of effect, acute or chronic, is a function of the pollutant, its ambient concentration, pathway of exposure, duration of exposure, and the age, sex, reproductive condition, nutritional status, and health of the organism at the time of exposure.

As mentioned earlier, studies on the effects of air emissions on wildlife are few. In addition, information on the level of exposure, pathways of contamination, symptoms observed, and other facts are often lacking. Most studies on laboratory animals have emphasized the effects of single pollutants at acute levels, although most ambient conditions involve a combination of pollutants at chronic levels. In spite of these information gaps, a number of ecological and physiological responses of wildlife to air emissions can be identified by combining information on effects observed on wildlife and known effects on domestic and laboratory animals (Table 3). The specific responses of wildlife and other animals to air emissions depend on the specific contaminant (Table 4). For example, some pollutants cause changes in the blood chemistry or physiology of animals while others do not. Photochemical oxidants affect the neutrophile and lymphocyte counts, whereas sulfur dioxide affects the blood Vitamin C. The most commonly affected system, as evidenced by the known effects of air emissions, is the respiratory system. The central nervous, pulmonary, and gastrointestinal systems are next in descending order of importance (Table 5).

Wildlife effected by air emissions may show abnormal behavior as a first indication of a problem. Abnormal behavior may range from listlessness and lethargy to violent movements (Table 6). Certain abnormal behaviors are symptomatic of specific poisoning, e.g., abnormal behaviors associated with lead poisoning. Other abnormal behaviors such as lameness in animals are not pollutant-specific. Abnormal behaviors observed in wildlife in and near emission sources strongly suggests potential contamination. Field biologists should be aware of abnormal behavior in wildlife as potential indicators of air pollution problems. A recent study by Richkind (1979) indicates that chronic exposure of small rodents (Peromyscus californicus) to air emissions (ozone) can cause genetic changes.

Table 3. Responses of Wildlife to Air Emissions (Newman 1975)

Ecological responses	Physiological responses
Change in population numbers	Changes in blood chemistry or physiology
Change in spatial distribution	Changes in cellular enzymes
Change in appearance	Changes in energy requirements for normal activities
Change in birth rate	Change in growth rates
Change in death rate	Change in genetic resistance
Abnormal behavior	Lowered resistance to natural environmental stress
	Residue accumulation
	Tetragenic, mutagenic, or carcinogenic effects

Table 4. Documented Responses of Birds and Mammals
(Domestic and Laboratory Animals and Wildlife)
to Acute and Chronic Exposure to Selected Air Emissions (Modified from Newman 1975)

Responses	Selected air pollutants																												
	Arsenic	Asbestos	Barium	Beryllium	Boron	Cadmium	Carbon Monoxide	Chromium	Fluoride	Hydrocarbons	Hydrochloric Acid	Hydrogen Sulfide	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Nitrogen Dioxide	Particulates[a]	Phosphorus	Photochem. Oxid.	Selenium	Sulfur Dioxide	Vanadium	Zinc
Changes in population numbers	●	●				●			●			●								●		●		●		
Changes in blood chemistry or physiology	●			●		●	●					●		●			●	●	●	●		●		●	●		
Changes in cellular enzymes	●			●					●	●	●		●						●	●	●	●		●		●
Changes in external appearance	●		●						●			●		●			●		●	●			●			
Change in population distribution									●											●				●		
Change in death rate (in free living animals)	●	●		●	●	●			●			●		●						●		●	●	●		
Change in birth rate	●													●								●				
Change in growth rate				●					●		●			●					●					●		
Change in genetic resistance																				●		●	●			
Abnormal behavior	●		●	●	●		●	●	●	●		●		●	●	●	●		●		●	●	●	●	●	●
Physiological changes observed in autopsy and histological analysis	●	●				●	●		●			●		●	●			●		●	●		●		●	●
Lowered resistance to natural environmental stress	●								●										●	●		●		●		
Residue accumulation in body tissues	●	●		●	●	●	●	●	●			●	●	●	●	●	●		●	●	●		●		●	●
Tetragenic, mutagenic, or carcinogenic		●	●	●		●		●										●				●	●			

[a] Particulates refer to unidentified pollutants.

Table 5. The Major Biological Systems of Animals Affected by Selected Air Emissions (Newman 1975)

Selected air emissions	Major biological systems of animals								
	Eyes	Central nervous system	Circulatory system	Gastrointestinal system	Hepatic system	Pulmonary system	Respiratory system	Renal system	Skeletal & dental system
Asbestos						●			
Arsenic				●			●		
Barium		●				●			
Beryllium							●		●
Boron		●			●		●		
Cadmium			●		●	●		●	
Carbon monoxide		●							
Chromium				●			●		
Fluoride								●	●
Hydrocarbons	●						●		
Hydrochloric acid	●						●		
Hydrogen sulfide		●		●			●		
Iron							●		
Lead		●		●					
Manganese		●							
Mercury				●		●			
Molybdenum				●	●		●	●	
Nickel									
Nitrogen dioxide		●				●			
Particulates[a]						●			
Phosphorus							●		
Photochem. oxid.	●						●	●	
Selenium		●		●		●	●		
Sulfur dioxide	●								
Vanadium			●				●		
Zinc				●		●	●	●	

[a] Particulates refer to unidentified pollutants.

Table 6. Abnormal Behaviors of Birds and Mammals (Domestic and Laboratory and Wildlife) Caused by Selected Air Emissions (Newman 1975)

Selected air emissions	Observed abnormal behavior
Arsenic	Incoordination of gait, muscular paralysis
Barium	Incoordination of movements, twitching, tremors, muscular paralysis
Beryllium	Temporary lethargy in dogs
Boron	Incoordination, tremors, listlessness, coma
Carbon monoxide	Incoordination of gait and movements, reduced appetite in chickens, impairment of learned activities in rats
Chromium	Stiffness, loss of appetite
Fluoride	Lameness, stiffness, weakness
Hydrocarbons	Dizziness, fatigue, loss of appetite
Hydrogen sulfide	Lethargy, gasping
Lead	Bellowing, roaring, staggering about with rolling eyes, frothing of mouth, grinding of teeth, ataxia, maniacal excitement, lethargy, loss of appetite, delirium
Manganese	Lethargy, tremors
Mercury	Incoordination of movements, paralysis, anorexia, lethargy, blindness
Molybdenum	Stiffness in legs and back
Phosphorus	Restlessness, nervousness
Selenium	Abnormal movement and posture, fear, nervousness, opisthotonus

WILDLIFE AS BIOLOGICAL INDICATORS OF AIR EMISSIONS

Wildlife species have good potential as biological indicators of air pollution for several reasons: (1) they integrate all environmental conditions both natural and man-made in their responses, (2) they can show pathway points of accumulation and stress in natural and man-influenced ecosystems, and (3) they can be used as biological standards to verify the physical and chemical standards of air quality. Several wildlife species have been suggested as biological indicators of air pollution. Pigeons (Tansey and Roth 1970) and urban rats (Selikoff and Hammond 1968) have been proposed for biological monitoring of lead and asbestos. Sparrows (McArn et al. 1974), ducks, and wild hares (Novakova and Roubal 1971) have been proposed as biological indicators of sulfur dioxide and particulates. Based on the known responses of wildlife and domestic animals to air emissions (Newman 1975), and suggested monitoring groups for other pollutants (Jenkins 1971), five wildlife groups are proposed as indicators of air pollution: (1) sentinel species, (2) bioassay organisms, (3) general detectors, (4) thrivers, and (5) accumulators. These groups are defined below.

Sentinel Species--Highly sensitive wildlife species that show a quick and characteristic response to low concentrations of a given air pollutant. These species act as "early warning" species.

Bees are extremely sensitive to fluoride and sulfur dioxide. Fluoride concentrations in vegetation, that are not harmful to man, domestic animals, or wildlife, are lethal to bees (Dewey 1973). A classic example of a sentinel organism is the canary (Serinus canaria), which miners used to detect the presence of coal gas, especially carbon monoxide. The bird becomes unconscious at concentrations not harmful to the miners. After being taken into clean air, the canaries recover.

Bioassay Organisms--Selected wildlife species whose ecology, physiology, and behavior are well known and whose specific and characteristic responses can be used to detect the presence of a particular pollutant, its concentration in the environment, or both.

This group of indicators contains wildlife species that can give the most precise measure of the presence and effects of an air pollutant. Correlations can be established between a given pollutant, its ambient concentration, and the particular ecological or physiological response of these wildlife species. Although no correlations have been established, well-studied game species such as deer, rabbits, ducks, pheasants, and quail would make good subjects for such correlations. White-tailed deer (Odocoileus virginianus) and wild turkey (Melegaris gallopavo) have been evaluated as bioassay organisms of disease (Trainer 1973). Their physiology and life histories are well known. In Czechoslovakia, hares, pheasants (Phasinus colchicus), and ducks (Anas sp.) are being intensively studied for possible use as these kinds of indicators of air emissions.

General Detectors--Lesser known wildlife species that show a reasonably characteristic response to air pollutants.

These species are wildlife groups whose response is indicative of air emission effects but not necessarily diagnostic, because of lack of information about the species or because of variability of the response of the species involved.

House martins (Delichon urbica) decline in their population density and geographic distribution because of air emissions (Newman and Novakova 1979). The abundance and distribution of these birds are also affected by natural factors such as weather and food supply. Therefore, their response (i.e., reduction in numbers) does not have the diagnostic certainty required for bioassay species. However, they do show a general response to air pollution which can be monitored and correlated with air emission levels.

Thrivers--Wildlife whose presence or increased abundance indicates the occurrence of a particular air pollutant or an environmental condition associated with that pollutant.

In water pollution studies, this indicator type is well typified by the tubifex worms and other organisms which thrive in heavy organic pollution. A similar situation seems to exist with heavy air pollution. Plant pathologists often report abnormal or unexpected insect pest infestations of vegetation in areas with high air pollution. Spruce forests in Germany affected by fluoride emissions have had heavy infestations of spruce gall lice and bark beetles (Wentzel 1965). In Poland, spruce forests affected by sulfur dioxide and nitrogen dioxide have had epidemics of sawflies (Sierpinski 1967). Darley (1966) reported heavy aphid infestation of an alfalfa field exposed to heavy cement dust from a cement factory. In California, bark beetles have been found to attack ponderosa pine forests at a higher rate when trees are injured by oxidants (Wood 1973). The response of these and other insects to air emissions is not completely understood but may be due to a combination of lowered plant resistance, reduction of natural predators, or both (Heagle 1973).

Accumulators--Wildlife species that concentrate detectable quantities of a given air pollutant in their tissues.

Many airborne pollutants accumulate in body tissues (Table 7). Even gaseous pollutants such as carbon monoxide, hydrogen sulfide, and nitrogen dioxide may remain in the circulatory system for several days after exposure. The most common sites for accumulation are the blood, skeletal tissue, liver, lungs, hair, and other keratinous tissues. Long-lived and sedentary species make the best accumulator organisms. Femurs of deer (Odocoileus sp.) have been used as standards for measuring fluoride contamination (Kay 1975). Even shorter-lived species such as small mammals have been used to monitor the distribution of heavy metals from air emissions (Gordon 1969a, b).

A diverse array of wildlife species accumulate airborne contaminants. Fluoride has been found in high concentrations not only in the bones of deer (Karstad 1967; Kay et al. 1975; Newman & Yu 1976) but also in cottontail

Table 7. Classification of Selected Air Emissions Based on Their Capacity to Accumulate in Body Tissue (Newman 1975)

Accumulators	Nonaccumulators
Asbestos	Barium
Arsenic	Hydrocarbons
Beryllium	Hydrochloric acid
Boron	Nickel (ingested)
Cadmium	Photochemical oxidants
Carbon monoxide[a]	Sulfur dioxide
Chromium	
Fluoride	
Hydrogen sulfide[a]	
Iron (Inhaled)	
Lead	
Manganese	
Mercury	
Molybdenum	
Nickel (inhaled)	
Nitrogen dioxide[a]	
Particulates (unidentified)	
Phosphorus	
Selenium	
Vanadium	
Zinc	

[a] Temporary accumulation remaining detectable for only several days after exposure.

rabbits (Sylvilagus floridanus), hares (Lepus sp.), muskrats (Ondatra zibethica), ground squirrels (Citellus columbianus), woodchuck (Marmota monax), deer mice (Peromyscus sp.), voles (Microtus sp.) (Gordon 1969a, Karstad 1970) and sparrows (Passer domesticus) (Balazova and Hluchan 1969). High fluoride concentrations have also been observed in carnivores such as the red fox (Vulpes fulva) (Karstad 1970) and the barn owl (Tyto alba) (Newman, personal observation). Cadmium levels four times higher than normal have been found in house sparrows in Japan and a high mortality recorded (Nishino et al. 1973).

High concentrations of cadmium have also been found in the tissues of wild rabbits (Sylvilagus nuttali), ground squirrels (Citellus columbianus), and cricitid rodents near a smelter in Montana (Gordon 1969b). Sparrowhawks (Accipiter nisus) and song thrushes (Turdus philomelos), living near a lead zinc smelter in England, accumulated high levels of cadmium in their body tissues (Martin and Coughtrey 1975, 1976). The effects of this trophic-transmitted cadmium were not known. Airborne mercury from a chlor-alkali plant in England resulted in concentrations in the tissues of several small mammals (Apodemus sylvaticus and Clethrionomys glareolus) (Bull et al. 1977). With a few exceptions, the effects of this bioaccumulation in wildlife are not known.

A given wildlife species may possess one or more of these biological indicator characteristics.

INDIRECT EFFECTS OF AIR EMISSIONS ON WILDLIFE

The indirect effects of air emissions on wildlife include food web contamination and habitat degradation as well as adverse synergistic effects of air emissions with natural and other man-induced stresses. Adverse effects to wildlife may result from direct contamination of wildlife food webs by air emissions or contamination of these terrestrial food webs indirectly from contaminated soils and aquatic food webs (Figure 1). Injury and death may also occur if wildlife are exposed to toxic levels of air pollutants with other pollutants (e.g., pesticides) concentrated in these food webs.

Few studies have considered biological accumulation in wildlife strictly from an air pollution point of view. Dewey (1973) has reported biomagnification of fluoride in the insect food webs found near an aluminum plant in Montana. Newman and Murphy (1979) studied the trophic transfer of fluoride emitted from an aluminum plant in Washington. They observed differential accumulation of fluoride in the primary browse of black-tailed deer (Odocoileus hemionus). These deer heavily utilized two browse species that had the highest fluoride concentration of all the browse during the winter, the period of lowest nutrition for the deer. Severe fluorosis was observed in the population including dental disfigurement, abnormal tooth wear, and hyperostosis in long bones. Hirao and Patterson (1974) reported the bioaccumulation of lead from urban areas through the terrestrial food chain of remote watersheds in California. Similar bioaccumulation of metals has been observed in small mammals living in watersheds of the Northeastern United States which receive deposition of metals from industrial areas of the Midwest and Middle Atlantic States (Schlesinger and Potter 1974).

Soil ecosystems are a "sink" for many pollutants, including air emissions. Those wildlife species dependent upon the soil environment, such as burrowing and litter-inhabiting forms, may be quite sensitive to soil contamination caused by air emissions. Air emissions can cause reductions in soil organisms and shifts in trophic structures. Freitag and Hastings (1973) observed an inverse relationship between ground beetle population numbers and sulfur dioxide emissions levels in the vicinity of a pulp mill (Figure 2). Lime dust emissions have been implicated in changing the soil pH around industrial locations in Germany. This alteration of the soil environment caused a reduction in the population density of existing nematode populations and changes in the species compositions. A shift in trophic structure from a semiparasitic-dominated food web to a saprophage-predatory nematode food web was observed (Bassus 1968). Other studies have shown that a reduction or change in decomposers can result in a decrease in litter decomposition and nutrient cycling (Jackson and Watson 1977). In the long term, these changes in decomposition and cycling can alter the habitat structure and food supplies of wildlife.

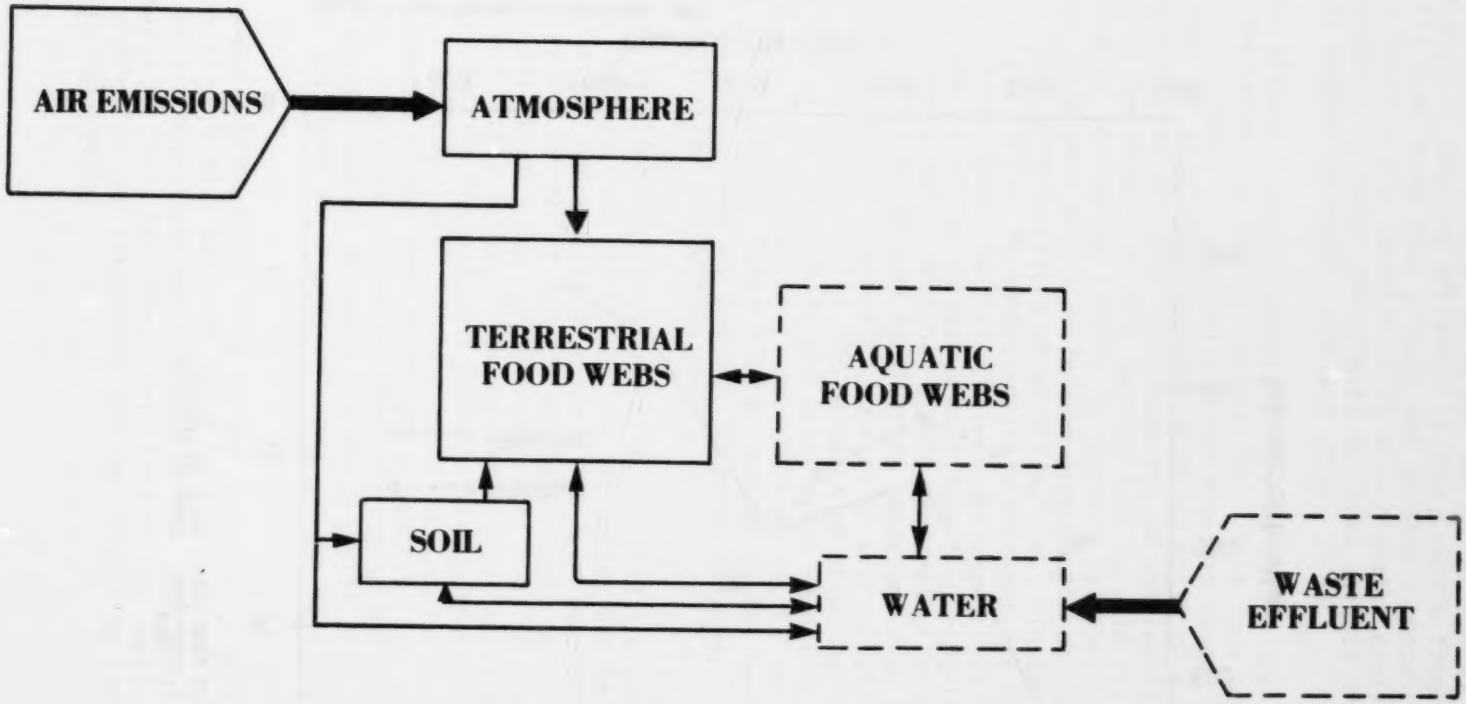


Figure 1. Potential pathways of contamination of terrestrial food web.

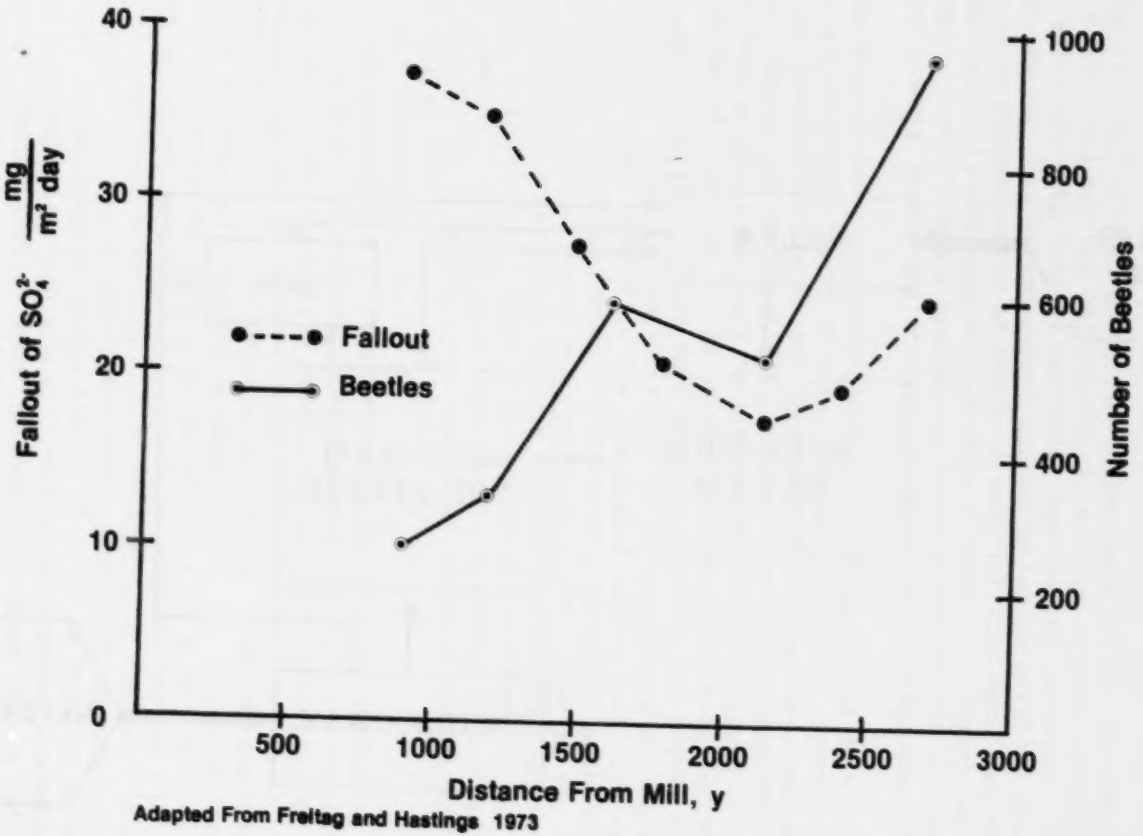


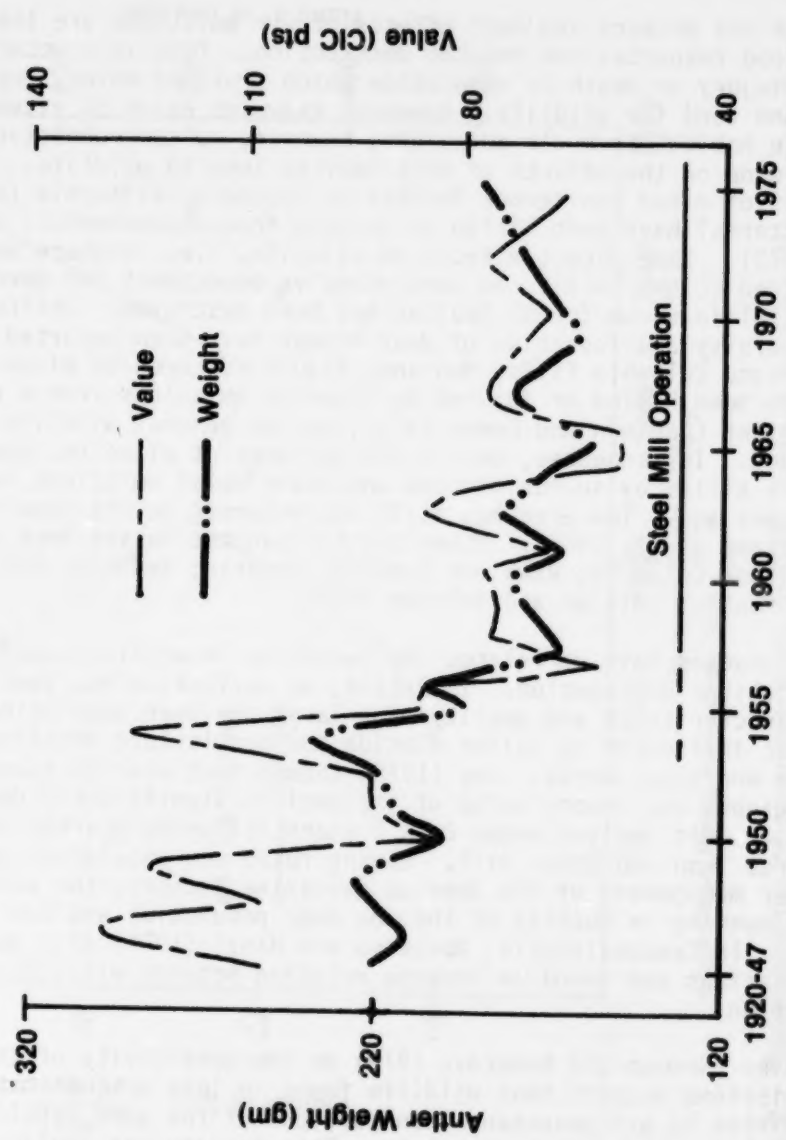
Figure 2. Relationship of average annual SO_4^{2-} fallout and beetle population samples near a kraft mill in Ontario, Canada.

Heavy metal contamination of soils has led to biological magnification in wildlife food chains. Studies of levels of heavy metals from vehicular traffic in soils have shown that primary and secondary vertebrate consumers can accumulate these metals (Scanlon 1979) with highest levels in the secondary consumers. Although the effects on these animals are not known, the observed levels suggest potential problems (Clark 1979).

Two of the primary indirect effects of air emissions are the loss of wildlife food resources and habitat destruction. This loss occurs as the result of injury or death to vegetation which provides cover, reproductive habitat, and food for wildlife. Numerous examples exist of extensive damage to wildlife habitat from air emissions; however, no comprehensive assessments have been made on the effects of this habitat loss to wildlife. For example, large areas of mixed coniferous forests in southern California (over 40,000 hectares) have been killed or injured from photochemical oxidants (Taylor 1973). Some direct effects on wildlife, i.e., bighorn sheep, have been recorded (Light 1973). No comprehensive assessment has been made of the loss of wildlife whose forest habitat has been destroyed. Shifts in small mammal diversity and reduction of deer browse have been reported (Taylor 1973). Around Columbia Falls, Montana, 37,000 hectares of mixed coniferous forest have been killed or injured by fluoride emissions from a nearby aluminum plant (Carlson and Dewey 1971), but no general wildlife assessment was recorded. In Tennessee, over 2,800 hectares of mixed deciduous-coniferous forest were killed by sulfur dioxide and heavy metal emissions from a smelter over 70 years ago. The area has still not returned to its previous natural state (Witkamp et al. 1966). Other similar habitat losses were recorded at Trail, British Columbia; Wawa and Sudbury, Ontario; Redding, California; and Anaconda, Montana (Miller and McBride 1975).

Two studies have correlated the reduction in wildlife quality with wildlife habitat degradation. In Poland, an evaluation has been made of the antler characteristics and quality of a large roe deer population living in a pine forest influenced by sulfur dioxide and particulate emissions from a large iron and steel works. Jop (1979) showed that over 50 years, the length, volume, weight, and trophy value of the antlers significantly declined (Figure 3). This decline began 2 to 3 years following startup and operation of the large iron and steel mill. Having ruled out population genetic changes or improper management of the deer as causative factors, the author concluded that the lowering in quality of the roe deer population was due to air emissions. In Czechoslovakia, Novakova and Hanzl (1974) also assessed the roe deer populations and found an inverse relation between wildlife quality and air pollution.

Studies (Newman and Novakova 1979) on the sensitivity of the house martin to air emissions suggest that wildlife found in less optimal habitats may be more sensitive to air emissions than portions of the same population found in more suitable parts of their habitats. This finding has implications especially for endangered and threatened species inhabiting limited and generally sub-optimal habitat.



Adapted From Jop, 1979

Figure 3. Change in roe deer antler weight and value in Niepolomice Forest, Poland.

It is difficult to generalize about the effects of air emissions on wildlife habitat because of the specificity of the responses of plants to air pollution (Hindawi 1970; Smith 1974; Davis and Wilhour 1976). However, some common patterns seem to exist. Injurious air emissions will cause a reduction in vegetative species diversity and species numbers. Higher-order ecosystems such as forests appear to be more sensitive to air emissions than lower-order systems, such as shrub ecosystems, which may be more sensitive than herbaceous ecosystems (Woodwell 1970; Smith 1974).

If these generalizations are correct, then there are several implications for wildlife. Injurious air emissions will change the wildlife habitats and ultimately the wildlife species composition. A "Vertebrate-Habitat-Dependency" matrix has been developed by Miller and others (Light 1973) for assessing the potential change in wildlife species composition because of the effects of oxidant emissions on mixed coniferous forests in southern California. Those wildlife species dependent upon forest habitat are likely to be more affected than wildlife species in simpler habitat types.

Wildlife species that have more specialized food or habitat requirements will likely be most affected when their food or habitat resource is damaged or reduced. Numerous examples exist of wildlife groups with narrow or specialized niches. Caribou (Rangifer sp.) are dependent upon lichens, which are sensitive to sulfur dioxide. The Everglades Kite (Rostrhamus sociabalis) depends upon the apple snail (Pomacea sp.). The loss of lichens or snails would lead to immediate effects on caribou and kites, respectively.

The synergistic interactions of air emissions with natural factors should be included in considering the indirect effects of air emissions. Air emissions may not be lethal by themselves but may lower the health and resistance of wildlife so that other factors such as natural stresses may result in further injury or death. Detailed studies on the health of wild hares have been conducted in Czechoslovakia. Hares from areas of high sulfur dioxide emissions (up to 0.35 mg/m^3) and fly ash depositions (up to 301 $t/km^2/yr$) have a more acid urine compared to hares from pollution-free areas. Animals from areas with heavy cement dust deposition (up to 501 $t/km^2/yr$) have a more basic urine (Novakova 1970). Changes in the calcium-phosphorus ratio of the blood are also observed.

In the areas of heavy sulfur dioxide and fly ash, there is a calcium deficiency close to a hypocalcemic condition. This difference is greater in younger hares and adult females. The concentration of phosphorus in the blood increases in adult hares, especially males (Novakova & Roubal 1971). Associated with variations in calcium and phosphorus levels in the blood of hares are changes in the erythrograms of these animals. Hypoproteinesis is found in hares from areas of heavy air pollution, including declines in albumins, α-globins, and β-globins. These changes in erythrograms are comparable with those observed in animals with infections or allergic reactions (Novakova et al. 1973). Along with these physiological changes are changes in the age structure of these hare populations. In regions having high concentrations of sulfur dioxide and fly ash, the ratio of 1-year-old hares to adult hares is 30 percent below that observed in pollution-free areas. In areas with heavy

cement dust, the ratio of 1-year-old hares to adult hares is 35 percent greater than in control areas (Novakova 1969). The particular relationship between the differential survival in the two age classes of hares and air emission levels is not known.

In Czechoslovakia air emissions were also found to influence some wildlife diseases in an unexpected way. Nematode infections of pheasants and protozoan infections of hares were less prevalent in areas of heavy air pollution. The incidence of syngamosis (gapeworm disease) in pheasants declined by 50 percent when sulfur dioxide emissions exceeded 0.15 mg/m^3 and fly ash deposition was between 150 to 300 $tons/km^2/year$. Nematode infections disappeared completely at sulfur dioxide emission levels above 0.35 mg/m^3 and fly ash deposition rates above 501 $tons/km^2/year$ (Novakova and Tremmlova 1973). The incidence of coccidiosis in hares showed a similar relationship. Although the cause for the decline in the incidence of syngamosis is not known, it is suspected that the intermediate hosts of these parasitic nematodes, or the nematodes themselves, are adversely affected by sulfur dioxide and fly ash, thereby reducing the chance for infection in pheasants (Novakova, personal communication).

No extensive evaluation has been made of the general health of the deer populations affected by fluoride emissions. In Washington, the deer that were sampled were in poor health because of fluorosis. Several of the severely affected deer had their molars and premolars worn down to and even below the gum line (Newman and Yu 1976; Newman and Murphy 1979). In cattle, this condition leads to impairment of food intake and utilization. Besides abnormal tooth wear Karstad (1967) observed a high incidence of fractured jaws in fluoride-contaminated deer. Although no information was reported on the survival of these deer, injuries such as abnormal tooth wear and jaw fracturing would likely lead to infections and nutritional problems. For wildlife, such conditions would lead to higher mortality rates during times of stress. Hais and Masek (1969) found that arsenic contamination of red and roe deer severely weakened the animals through emaciation and loss of hair so that many of the deer froze to death during the winter.

One area of wildlife study which has been completely overlooked is the combined effects of pesticides and industrial air emissions. Death and injury to wildlife from the indiscriminate use of pesticides are well-known. Most wildlife populations carry detectable amounts of pesticides and their chemical derivatives in their tissues (Stickel 1975). Although the synergistic effects of air emissions and pesticides on wildlife populations are not known, they are likely to be adverse.

CONCLUSIONS

The effects of air emissions on wildlife can be dramatic, such as the die-off of a large population of songbirds observed by Harris (1971), or quite subtle, such as small shifts in the age structure of hares as reported by Novakova (1969). In many cases the effects are debilitating, and can lead to death during periods of natural stress. Industry-related diseases such as fluorosis and arsenic poisoning are common. Some air pollutants produce symptoms similar to physiological stress and anaemia. These conditions can also lower the chances of survival of wildlife during times of natural stress. When population studies have been made, significant reductions in numbers of wildlife have been correlated with industrial air pollution. The major pathways of contamination of wildlife by air emissions are inhalation, adsorption, and ingestion, with the latter being the most important. Wildlife can serve as biological indicators of environmental quality because of their observed sensitivity to air emissions.

The known effects of air emissions on wildlife resources have several points of importance for wildlife biologists and managers. Air emissions can reduce wildlife populations directly through injury or death or indirectly through contamination of their food web or through loss of habitat. These effects are especially critical for intensively managed populations such as endangered or threatened species that need to maintain a viable reproductive population size or that depend upon a few key habitat factors. Species designated as "rare" or of "special concern" are often populations at the edge of their range. These populations may also be more vulnerable to air emissions than populations of the same species living near the center of their range.

If wildlife management areas are in proximity to air emission sources, the stocking and management programs for game and other wildlife species may be affected through lowering the habitat quality by injury or death to important wildlife habitat resources or by lowering the resistance of game populations to natural environmental stresses.

Assessment and monitoring of the effects of air emissions requires a dual understanding of the physical and chemical behavior of air emissions as well as a knowledge of wildlife ecology and toxicology.

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